

TRANSMITTAL LETTER TO THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)
CONCERNING A FILING UNDER 35 U.S.C. 371

Studien 277-KGB

U.S. APPLICATION NO. (If known, see 37 CFR 1.5)

09/700401

INTERNATIONAL APPLICATION NO.

PCT/EP99/03287

INTERNATIONAL FILING DATE

12. Mai 1999 (12.05.99)

PRIORITY DATE CLAIMED

16. Mai 1998 (16.05.98)

TITLE OF INVENTION
SEE APPENDIX

APPLICANT(S) FOR DO/EO/US

WILHELM-FRIEDRICH MATIER ET AL.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
 2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
 3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
 4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
 5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
 - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☒ has been transmitted by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
 6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
 7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
 - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☐ have been transmitted by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☐ have not been made and will not be made.
 8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
 9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
 10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).
- Items 11. to 16. below concern document(s) or information included:
11. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
 12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
 13. ☒ A **FIRST** preliminary amendment.
☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
 14. ☐ A substitute specification.
 15. ☐ A change of power of attorney and/or address letter.
 16. ☒ Other items or information:
 - Verified Statement (Declaration) Claiming Small Entity Status
 - Specification: Description (pgs. 1-10); Claims (pgs. 11-12); Abstract (pg. 13)
Description of Figures 1-3 (pg. 14); Figure 1; Figure 2; Figure 3
 - Copy of WO 99/59716
 - Copy of the International Search Report
 - Marked up Claims
 - Clean Claims

U.S. APPLICATION NO. 09/700401 INTERNATIONAL APPLICATION NO. PCT/EP99/03287				ATTORNEY'S DOCKET NUMBER Studien 277-KGB	
17. <input type="checkbox"/> The following fees are submitted: BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) : Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO \$970.00 International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO. \$860.00 International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO \$760.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) \$670.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) \$96.00 <div style="text-align: right; margin-top: 5px;">ENTER APPROPRIATE BASIC FEE AMOUNT =</div>				<div style="text-align: center; font-weight: bold; font-size: 1.2em;"> CALCULATIONS PTO USE ONLY </div> <div style="font-size: 1.5em; font-weight: bold; margin-top: 10px;"> 532 Rec'd PCT/PTO 14 NOV 2000 </div>	
Surcharge of \$130.00 for furnishing the oath or declaration later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				\$	
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	14 - 20 =	0	X \$18.00	\$ 0	
Independent claims	1 - 3 =	0	X \$80.00	\$ 0	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ \$ 270.00	\$ 0	
TOTAL OF ABOVE CALCULATIONS =				\$ 860.00	
Reduction of 1/2 for filing by small entity, if applicable. A Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28).				\$ 430.00	
SUBTOTAL =				\$ 430.00	
Processing fee of \$130.00 for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				\$	
TOTAL NATIONAL FEE =				\$ 430.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property				\$	
TOTAL FEES ENCLOSED =				\$ 0	
				Amount to be:	\$
				refunded	
				charged	\$ 430.00

- a. ☐ A check in the amount of \$ _____ to cover the above fees is enclosed.
- b. ☒ Please charge my Deposit Account No. 14-1263 in the amount of \$ 430.00 to cover the above fees.
A duplicate copy of this sheet is enclosed.
- c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any
overpayment to Deposit Account No. 14-1263. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

Kurt G. Briscoe
 Norris McLaughlin & Marcus PA
 220 East 42nd Street
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 New York, New York 10017
 (212) 808-0700

SIGNATURE:

Kurt G. Briscoe

NAME

33,141

REGISTRATION NUMBER

Applicant or Patentee: Studiengesellschaft Kohle mbH et al Attorney KGB

Serial or Patent No. : _____ Docket No.: _____

Filed or Issued: _____

For: Combinational Method for Microgram-Scale Production and Characterization of Crystalline and Amorphous Libraries of Materials

VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(f) AND 1.27(d) - NONPROFIT ORGANIZATION

I hereby declare that I am an official empowered to act on behalf of the nonprofit organization identified below:

NAME OF ORGANIZATION Studiengesellschaft Kohle mbH

ADDRESS OF ORGANIZATION Kaiser-Wilhelm-Platz 1
45470 Mülheim an der Ruhr, Germany

TYPE OF ORGANIZATION Trustee for the Max-Planck-Institut für Kohlenforschung,
Kaiser-Wilhelm-Platz 1, 45470 Mülheim an der Ruhr,
Germany
☐ University or other institution of higher education

I hereby declare that the nonprofit organization identified above qualifies as a nonprofit organization as defined in 37 CFR 1.9(e) for purposes of paying reduced fees under section 41(a) and (b) of Title 35, United States Code with regard to the invention entitled see above by inventor(s) Majer et al described in

☒ the specification filed herewith
☐ application Serial No. _____, filed _____
☐ patent no. _____, issued _____

I hereby declare that rights under contract or law have been conveyed to and remain with the nonprofit organization with regard to the above identified invention.

If the rights held by the nonprofit organization are not exclusive, each individual, concern or organization having rights to the invention is listed below* and no rights to the invention are held by any person, other than the inventor, who could not qualify as a small business concern under 37 CFR 1.9(d) or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e). *NOTE: Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)

FULL NAME _____

ADDRESS _____

☐ INDIVIDUAL ☐ SMALL BUSINESS CONCERN ☐ NONPROFIT ORGANIZATION

FULL NAME _____

ADDRESS _____

☐ INDIVIDUAL ☐ SMALL BUSINESS CONCERN ☐ NONPROFIT ORGANIZATION

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28).

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

Prof. Dr. E. Ziegler

NAME OF PERSON SIGNING

NAME OF PERSON SIGNING

Studiengesellschaft Kohle mbH

TITLE OF ORGANIZATION

TITLE OF ORGANIZATION

Kaiser-Wilhelm-Platz 1,
45470 Mülheim an der Ruhr, DE

ADDRESS OF PERSON SIGNING

ADDRESS OF PERSON SIGNING

E. Ziegler
SIGNATURE

SIGNATURE

November 7, 2000

Date

Date

Studiengesellschaft Kohle mbH

09/700401

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Studien 277-KGB
Zi/D

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICANTS : WILHELM-FRIEDRICH MAIER ET AL.
SERIAL NO. : TO BE ASSIGNED
FILED : HEREWITH
FOR : COMBINATIONAL METHOD FOR MICROGRAM-SCALE
PRODUCTION AND CHARACTERIZATION OF
CRYSTALLINE AND AMORPHOUS LIBRARIES OF
MATERIALS
ART UNIT : UNASSIGNED
EXAMINER : UNASSIGNED

November 14, 2000

Hon. Commissioner of Patents
Washington, D.C. 20231

PRELIMINARY AMENDMENT

SIR:

Prior to examination, please amend the above-identified application as follows:

IN THE SPECIFICATION:

Insert as the first sentence: -- This application is a 371 of PCT/EP99/03287, which was
filed on May 12, 1999. --

IN THE CLAIMS:

Rewrite claims 4-6 to read as follows:

4. The method according to claim 1, wherein the reactor bottom plate, which consists of a material that scatters X-rays elastically, is identical with the library substrate on which the solids are adhesively deposited and constitutes the materials library together with the deposited calcined solids.
5. The method according to claim 1, wherein a subset of all solids deposited is subsequently transferred to a plastic sheet made of a X-ray transparent material and provided with an adhesive coating, which plastic sheet as a library substrate constitutes the materials library together with the solids transferred thereto.
6. The method according to claim 1, wherein the solids of the materials library are subsequently characterized by non-destructive analytical methods.

REMARKS

This amendment is being filed in accordance with the new rules of practice. Changes have been made in original claims 4-6 to eliminate multiple dependency. A clean version of

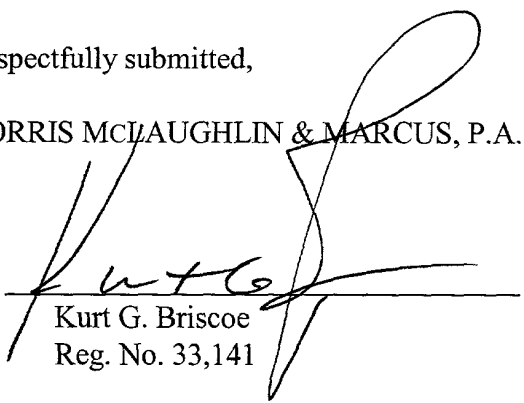
claims 4-6 appears above. A mark-up showing the changes to claims 4-6 in red pen is attached for the Examiner's convenience.

Early and favorable action is earnestly solicited.

Respectfully submitted,

NORRIS McLAUGHLIN & MARCUS, P.A.

By


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CLAIMS PENDING AS OF NOVEMBER 14, 2000

1. A method for the wet chemical preparation of a materials library comprising a large number of solids from reaction mixtures having different compositions, characterized in that the reaction mixtures are introduced, in a spatially separated way, into microreaction chambers in removable reaction plates in a reactor and reacted, the solids produced in the reactions being deposited in a spatially separated way on a removable reactor bottom plate.
2. The method according to claim 1, wherein the reaction mixtures are reacted in the form of solutions or suspensions in the microreaction chambers, which are introduced into the reaction plates in the form of isolated cavities as bores, at temperatures of up to 1000 °C and internal pressures of up to 1000 bar.
3. The method according to claim 1, wherein the solids deposited on the reactor bottom plate are subsequently freed from the supernatant liquid phase and calcined.
4. The method according to claim 1, wherein the reactor bottom plate, which consists of a material that scatters X-rays elastically, is identical with the library substrate on which the solids are adhesively deposited and constitutes the materials library together with the deposited calcined solids.
5. The method according to claim 1, wherein a subset of all solids deposited is subsequently transferred to a plastic sheet made of a X-ray transparent material and provided with an adhesive coating, which plastic sheet as a library substrate constitutes the materials library together with the solids transferred thereto.

6. The method according to claim 1, wherein the solids of the materials library are subsequently characterized by non-destructive analytical methods.
7. The method according to claim 4, wherein the reactor bottom plate consists of a single-crystal slice, preferably of Si, Cu, quartz, rutile, anatase, zirconia, Ge, Al, sapphire, Fe, Ti, Zr, Co, Ni or Sn.
8. The method according to claim 7, wherein the reactor bottom plate consists of a (711) Si single-crystal wafer.
9. The method according to claim 4, wherein reflecting microarea X-ray diffraction is employed as an analytical method.
10. The method according to claim 5, wherein penetrating microarea X-ray diffraction is employed as an analytical method.
11. The method according to claim 5, wherein Kapton, Kevlar, Teflon, Mylar, PVC, polyethylene, polypropylene, polycarbonate, Al, Be or Mg in a layer thickness of $< 100 \mu\text{m}$ is employed as said X-ray transparent material.
12. The method according to claim 5, wherein said layer thickness is below $10 \mu\text{m}$.
13. The method according to claim 1, wherein said reactor has a layered design, essentially comprising: a reactor bottom plate, on top thereof a lower part of the reaction plate, made of an inert material, having bores of from 0.05 to 20 mm in diameter, on top thereof an upper part of the reaction plate, made of a hard material, having identical bores, on top thereof a sealing layer, on top thereof a layer of a hard material with which the reactor layers are compressed and sealed using suitable devices.
14. The method according to claim 13, wherein said inert material consists of Kapton, Teflon, graphite, Kevlar, Mylar or steel.

MARK-UP SHOWING CHANGES MADE TO
CLAIMS 4-6 ON

- 11 -

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11-14-2000

CLAIMS:

1. A method for the wet chemical preparation of a materials library comprising a large number of solids from reaction mixtures having different compositions, characterized in that the reaction mixtures are introduced, in a spatially separated way, into microreaction chambers in removable reaction plates in a reactor and reacted, the solids produced in the reactions being deposited in a spatially separated way on a removable reactor bottom plate.
2. The method according to claim 1, wherein the reaction mixtures are reacted in the form of solutions or suspensions in the microreaction chambers, which are introduced into the reaction plates in the form of isolated cavities as bores, at temperatures of up to 1000 °C and internal pressures of up to 1000 bar.
3. The method according to claim 1, wherein the solids deposited on the reactor bottom plate are subsequently freed from the supernatant liquid phase and calcined.
4. The method according to ^{claim} ~~claims~~ 1 to 3, wherein the reactor bottom plate, which consists of a material that scatters X-rays elastically, is identical with the library substrate on which the solids are adhesively deposited and constitutes the materials library together with the deposited calcined solids. ✓
5. The method according to ^{claim} ~~claims~~ 1 to 3, wherein a subset of all solids deposited is subsequently transferred to a plastic sheet made of a X-ray transparent material and provided with an adhesive coating, which plastic sheet as a library substrate constitutes the materials library together with the solids transferred thereto. ✓

SMB

Combinatorial Method for the Preparation and Characterization of Libraries of Crystal-
line and Amorphous Materials on a Microgram Scale

The present invention relates to a method for the wet chemical preparation of materials libraries consisting of a large number of solids, the solids being deposited from reaction mixtures in microreaction chambers onto a bottom plate which simultaneously serves as the library substrate.

The narrowest bottleneck in the development of new active substances, polymers and materials is the discovery of suitable new leading structures. In fields of organic, biochemical and pharmaceutical chemistry, combinatorics has become established within a few years as an important tool for the development of new compounds (e.g., Special issue: Combinatorial Chemistry, Acc. Chem. Res., 1996, 29; G. Lowe, Chemical Society Reviews, 1995, 24 (5), 309; S.R. Wilson, A.W. Czarnik, Combinatorial Chemistry - Synthesis and Application, John Wiley & Sons, 1997). In contrast, only a few examples of using a combinatorial search for materials are known in the field of inorganic solid synthesis and materials research or technical catalyst development. The preparation of materials libraries by combinatorial syntheses has been reported for finding new superconducting materials (X.-D. Xiang et al., Science, 1995, 268, 1738), new magnetoresistant materials (G. Briceno et al., Science, 1995, 270, 273) and new luminescent materials (E. Danielson et al., Science, 1998, 279, 837). A common feature of all these methods is that the application of the substances as thin films by electron beam vaporization or RF sputtering under reduced pressure results in the formation of a materials library. The shape is created by a physical mask, which already resulted in libraries of as much as 25,000 materials. The first combinatorial production of a materials library by a wet chemical method using ink jet technology

resulted in the development of luminescent materials (D. Sun et al., *Adv. Mater.* 9, 1046-1049, 1997). There is a drawback in that this method can only be employed at normal pressure and low temperatures.

Many of the materials known to date, especially the porous substances important to catalysis, can be prepared exclusively by a wet chemical method, often by a hydrothermal process (e.g., M.W. Anderson et al., *Angew. Chem.*, 1995, 107, 1115; D.P. Serrano et al., *Microporous Materials*, 4 (1995), 273). These methods are distinguished only by the selected ranges of temperature and pressure, the variation of the stoichiometric proportions of the selected precursors, and the template molecules selected (L.D. Rollmann, *Inorganic Compounds with unusual Properties-II*, 1979, 387). Depending on the sample volume and experimental procedure, a synthesis under hydrothermal conditions takes from 2 hours to several weeks. This is followed by the further processing and characterization of the product. The most important analytical method is powder diffraction for elucidating the phase structure. Of particular importance to the application of such materials in fields such as catalysis or sensor technology is their pore architecture which can be controlled by the addition of template molecules in hydrothermal synthesis. To date, due to the high expenditure of time for one synthesis and the wide variety of possible mixed oxides and template molecules, a systematic and exhaustive examination of these classes of materials has been impossible. Due to the wide variety of possible polynary mixtures of oxide materials and the generally possible template molecules for influencing the pore architecture of such materials, a transfer of the methods of combinatorial chemistry to hydrothermal synthesis is attractive.

The first application of combinatorial methods in hydrothermal synthesis was reported by Akporiaye, Karlsson and Wendelbo (D.E. Akporiaye, I.M. Dahl, A. Karlsson, R. Wendelbo, *Angew. Chem.*, 1998, 110, No. 5, 629; D.E. Akporiaye, I.M. Dahl, A. Karlsson, R. Wendelbo, patent pending, Norwegian Application No. 97.0788). They developed an autoclave by means of which 100 hydrothermal syntheses (reaction volumes of 500 ml each) at temperatures of up to 200 °C can be performed simultane-

ously. There is a drawback in that this process does not produce a materials library, but the solids produced must be removed from the individual minireactors and individually characterized by standard methods. This kind of handling the samples after synthesis has proven very cumbersome and significantly limits the performance of this combinatorial approach.

We have now found that materials libraries with extremely low quantities of materials (reaction volumes of 2 μ l or less) can be prepared by a wet chemical method. Thus, a large number of reaction mixtures of different compositions are simultaneously reacted in microreaction chambers included in a plate ("reaction plate"), for example, in the form of bores, the solids produced being deposited on the bottom plate of the reactor. Subsequently, the solids are freed from the supernatant liquid phase and calcined whereby they adhere in a spatially separated way to the bottom plate. By appropriately selecting the material of the bottom plate of the reactor, it may also serve as the library substrate. Alternatively, the solids or subsets thereof may be transferred to a plastic sheet provided with an adhesive layer so that a printed materials library on another library substrate is formed.

Depending on the material selected for the reactor bottom plate or the sheet, different analytical methods can be employed for characterizing the solids, such as reflecting microarea X-ray diffraction, if the bottom plate is made of a material which will scatter X-rays elastically and cause a low scattering background. Suitable materials include single-crystal slices, preferably of Si, Cu, quartz, rutile, anatase, zirconia, Ge, Al, sapphire, Fe, Ti, Zr, Co, Ni or Sn, more preferably a (711) Si single-crystal wafer. Suitable for examination with penetrating microarea X-ray diffraction are X-ray transparent materials, such as Kapton, Kevlar, Teflon, Mylar, PVC, polyethylene, polypropylene, polycarbonate, Al, Be or Mg in layer thickness of $< 100 \mu\text{m}$, preferably $< 10 \mu\text{m}$.

The reactor for generating the materials libraries has a layered design: Over the bottom plate of the reactor, which may serve as the library substrate, there are provided at least two reaction plates of an inert material having bores of from 0.05 to

20 mm in diameter which serve as microreaction chambers. The topmost reaction plate consists of a hard material, e.g., steel. On top thereof, there is a sealing layer without bores, e.g., made of Teflon, and still on top, there is a layer of a hard material with which the reactor layers are compressed and sealed using suitable devices. When the materials employed are appropriately selected, reaction temperatures of up to about 1000 °C are possible; when Teflon is used for sealing, a maximum of 350 °C is possible.

The reactor can have very small dimensions and extremely small reactor volumes and meets the highest safety demands. A reasonable and practicable miniaturization of the materials library is currently limited only, on the one hand, by the focusability of the X-ray beam during the measurement of X-ray diffraction, and on the other hand, by the dimensions of the liquid dispensing means. While 10 samples per mm can already be analyzed with a minute X-ray beam diameter of 50 μm ($= 10,000 \text{ samples/cm}^2$), only 5 samples per mm can be realized for a dispensable sample quantity of 0.5 μl and a minireactor height of 10 mm ($= 2,500 \text{ samples/cm}^2 = 250,000 \text{ samples/dm}^2$).

The application of combinatorial techniques to synthesis optimizations, systematic variations of the compositions and preparation conditions enables a fast optimization of solid syntheses and a drastic speed-up of the discovery of new solids. Thus, the development of materials can be inexpensively performed in a normal laboratory without additional safety measures. Also, due to its small dimensions, the reactor can be handled without problems in glove boxes under inert gas, and when appropriately modified, it can be charged with reactive gases, such as ammonia, chlorine, methane, borane, HCl, hydrogen, oxygen or fluorine, hermetically sealed and thus employed for the synthesis of new materials.

An automated examination of all solids of a thus prepared materials library is possible, for example, by the phase identification of the individual materials using the commercial GADDS microdiffractometer of Bruker-AXS (M. Schuster, H. Goebel, Appl. Phys. 28 (1995), A270-A275; H. Goebel, PCT Int. Appl. WO 95/22758 A1). This concept enables a direct identification of the substances formed. The separate preparation of samples

for measurement is avoided. In addition to phase identification by non-destructive microarea X-ray diffraction, the complete library is available for other examinations, such as catalytic activity using IR-thermography (Maier, Holzwarth, DE A19757 754.7 of December 23, 1997), luminescence, magnetic resistance and other characterizations.

In particular, the method relates to the preparation or deposition of crystalline and amorphous solids from liquid phases, such as solutions, emulsions, suspensions or sols. Above all, suitable fields include sol-gel synthesis (C.J. Brinker, G.W. Scherrer, "Sol-Gel Science, the Physics and Chemistry of the Sol-Gel Process", Academic Press, New York 1990), hydrothermal syntheses (Kirk-Othmer (3rd) 6, 321), hydrometallurgy, decomposition of preceramic materials to produce hard materials (D. Segal, Chemical Synthesis of Advanced Ceramic Materials, Cambridge University Press, New York 1989) and polymerizations.

The method according to the invention is useful, for example, for the discovery of new materials in the field of inorganic solids, especially in the field of mixed oxides, mixed carbides, mixed nitrides and mixed borides. These materials are employed in many fields of everyday life and industrial production as lead-structures for catalysts, optical waveguides, coatings, semiconductors, superconductors, ferromagnetic materials, magnetic reluctors, optical materials, hard materials, luminescent and fluorescent materials, sensors, NLO materials, special materials and many more. Especially the class of substances including crystalline porous materials, such as zeolites or amorphous porous mixed oxides, mixed carbides or mixed nitrides, is of great interest to the industry. They are employed technically as catalysts for oil refinement in petrochemistry as well as for the preparation of pharmaceuticals, fine and bulk chemicals. A wide variety of oxidation reactions is catalyzed by them: aromatic hydroxylation, olefin epoxidation, ketone ammoxidation, alcohol oxidation and alkane oxyfunctionalization, to name but a few. Similarly promising are the stable amorphous mixed oxides whose properties are as important as those of the crystalline materials, but whose preparation is mostly simpler than that of the well-defined crystalline materials.

Example:

The combinatorial modification of a conventional laboratory titanium silicalite synthesis under hydrothermal conditions (UK Patent 2 071 071 B) is used as an example to show how a materials library of crystalline and amorphous materials can be prepared and analyzed with a minimum expenditure of time.

The reactor employed:

Figure 1 shows a construction drawing of the pressure-sealed reactor. In a cylindrical pressure vessel made of steel (total diameter: 40 mm, inner diameter: 24.5 mm) and having a height of 22.7 mm, there is provided a silicon single-crystal wafer of 22 mm diameter. By three screws, a steel plate with a Teflon insert is pressed onto this Si single-crystal wafer, the bores in the plate representing the reaction chambers. Figure 2 shows the pattern with the corresponding distances. The different reaction solutions are pipetted into this mask by means of a robot or by hand (1 to 2 μ l). As a seal for the reaction, a further Teflon disk follows which is again pressed against the remaining structure using a thick steel plate and three screws so that the whole assembly is pressure-sealed.

Experimental sample:

In a typical charge, 2.27 g (10.9 mmol) of tetraethyl orthosilicate (TEOS) is mixed with 75 mg (0.33 mmol) of tetraethyl titanate in a 10 ml vessel. To this solution is added with stirring 4 g (5 mmol) of a 25% by weight solution of tetrapropylammonium hydroxide, and stirring is continued for 1 h. After 5-6 h of heating to 80-90 °C, the alcohol produced is completely evaporated, and then distilled water is added to the solution to make 7.5 ml, and a typical reaction solution is obtained.

According to the information found in Table 1, 37 combinatorial modifications of the experiment were prepared.

Table 1

Bore	Mixture	Bore	Mixture
A1	Si : Ti : NPr ₄ OH 1 : 0,03 : 0,45	D5	Al : Ti : CTAB 1 : 0,05 : 0,1
A2	Si : Ti : NBu ₄ OH 1 : 0,03 : 0,45	D6	Al : Zr : NBu ₄ OH 1 : 0,2 : 0,4
A3	Si : Ti : NEt ₄ OH 1 : 0,03 : 0,45	D7	Al : Zr : NMe ₄ OH 1 : 0,2 : 0,4
B1	Si : Ti : NMe ₄ OH 1 : 0,03 : 0,45	E1	Al : Zr : NEt ₄ OH 1 : 0,2 : 1
B2	Si : Ti : C ₄ H ₉ N 1 : 0,03 : 0,45	E2	Al : Zr : CTAB 1 : 0,2 : 0,1
B3	Si : Ti : CTAB 1 : 0,03 : 0,045	E3	Ti : Zr : NBu ₄ OH 1 : 1 : 0,4
B4	Si : Ti : hexadecylamine 1 : 0.03 : 0.045	E4	Ti : Zr : NBu ₄ OH 1 : 1 : 0,4
B5	Si:Ti:hexadecylamine:NaOH 1 : 0.03 : 0.045 : 0.45	E5	Ti : Zr : NMe ₄ OH 1 : 1 : 0,4
C1	Si : Al : NPr ₄ OH 1 : 0,033 : 0,43	E6	Ti : Zr : NEt ₄ OH 1 : 1 : 1

C2	Si : Al : NPr ₄ OH 1 : 0,066 : 0,43	E7	Ti : Zr : CTAB 1 : 1 : 0,1
C3	Si : Zr : NPr ₄ OH 1 : 0,03 : 0,98	F1	Si : Ti : NPr ₄ OH 1 : 0,03 : 0,45
C4	Si : V : NPr ₄ OH 1 : 0,03 : 0,45	F2	Si : V : NPr ₄ OH 1 : 0,03 : 0,45
C5	Si : Zr : NMe ₄ OH 1 : 0,03 : 0,4	F3	Si : Ti : NEt ₄ OH 1 : 0,03 : 0,45
C6	Si : Zr : NMe ₄ OH 1 : 0,03 : 0,4	F4	Si : Zr : NPr ₄ OH 1 : 0,01 : 0,98
C7	Al : Ti : NMe ₄ OH 1 : 0,05 : 0,4	F5	Si : Al : NPr ₄ OH 1 : 0,1 : 0,43
D1	Al : Ti : NMe ₄ OH 1 : 0,05 : 0,4	G1	Si : Ti : NPr ₄ OH 1 : 0,03 : 0,45
D2	Al : Ti : NEt ₄ OH 1 : 0,05 : 1	G2	Al : Si : NPr ₄ OH 1 : 0,2 : 0,43
D3	Al : Ti : NEt ₄ OH 1 : 0,05 : 1	G3	Al : Si : NPr ₄ OH 1 : 0,1 : 0,43
D4	Al : Ti : CTAB 1 : 0,05 : 0,1		

Table 1: Composition of the material spots of the library in Figure 2. "Mixture" gives the molar ratio of the metal alkoxides employed (and thus the oxide materials in the forming product) to the template molecule employed. As sources of SiO₂, TiO₂, ZrO₂ and Al₂O₃, there were employed tetraethoxysilane (Si(OEt)₄, TEOS), Ti(OEt)₄, Ti(OⁱPr)₄ or Ti(OⁿPr)₄, Zr(OⁿPr)₄ and Al(O^{sec}Bu)₃. Since distilled water was added to the externally prepared samples to make 7.5 ml after evaporation of the alcohols, an excess of water : metal of 40 : 1 is present for hydrothermal synthesis in all samples.

A1 and F1 respectively contain the original sample described above. The bores A1-G3 (Figure 2) are filled with 1 to 2 µl of the charges from Table 1. "Mixture" gives the molar ratio of the metal alkoxides employed (and thus the oxide materials in the forming product) to the template molecule employed. Since distilled water was added

to the externally prepared samples to make 7.5 ml after evaporation of the alcohols, an excess of water : metal of 40 : 1 is present for hydrothermal synthesis in all samples.

The reaction is performed with the reactor closed at a temperature of 200 °C over a period of 36 h.

Posttreatment of the materials library:

The reaction is followed by lifting the top steel and Teflon plates, and the products in the microreaction chambers are separated from the mother liquor by removing the supernatant liquid using conventional techniques, such as porous magnesia sticks. Of course, this is ideally effected in one procedure using appropriate tools. Subsequently, the substances are repeatedly washed in the same way with 2 µl of distilled water. Thereafter, the open reactor with the products can be dried and, when Teflon is used as the reactor plate, calcined at a maximum of 350 °C, preferably 130 °C, which results in a good adhesion of the solids formed to the reactor bottom. After removing the two reaction plates of steel and the Teflon insert, the thus produced materials library (original bottom plate) can be further treated or examined. In the case of the zeolite synthesis as sought here, the materials library was annealed in a furnace at 600 °C for 10 h. If the products are to be analyzed in a vertical position, the adhesion of the samples can be improved by spraying a suitable amorphous varnish onto the library. It can subsequently be evaporated or oxidatively removed at elevated temperatures.

Identification of the solids:

The identification of the phases of the products formed was effected with a GADDS microarea X-ray diffractometer with a Göbel mirror and a HISTAR detector. The Si plate was attached to a xyz sample stage and then, after entering the scanning parameters and storage of the spots to be measured, it was measured in reflection in a fully automated manner. The powder diffractograms were recorded with a 500 µm collimator integrally over the whole spot area. Focusing the X-ray beam to as narrow as 50 µm with a high X-ray intensity is possible using bent Göbel mirrors. Thus, individual particles in the micrometer scale are accessible to X-ray analytical examina-

tion. Under the measuring conditions chosen, no reflections from the silicon sample holder are found. When a thin plastic sheet is used as the reactor bottom or when the library is transferred to a thin plastic sheet provided with an adhesive layer, the diffractogram can also be recorded in a transmission mode. The diffractograms obtained are conveniently stored for later evaluation and can be identified by hand or in a fully automated way using standard libraries for comparison.

The evaluation of the diffractograms showed that the spots highlighted in gray in Figure 2 contain crystalline fractions while all non-highlighted spots contain amorphous materials. The structure of the crystalline phases was identified by comparing their diffractograms with a diffractogram library. The reaction mixtures for producing the solids in spots A1 and F1 are in accordance with classical synthesis. In Figure 3, the powder record from the conventionally produced zeolite (top) is compared with the diffractograms of spots A1 and F1. The Figure proves that the microgram quantities of the materials library produced a material identical with that obtained by conventional synthesis.

CLAIMS:

1. A method for the wet chemical preparation of a materials library comprising a large number of solids from reaction mixtures having different compositions, characterized in that the reaction mixtures are introduced, in a spatially separated way, into microreaction chambers in removable reaction plates in a reactor and reacted, the solids produced in the reactions being deposited in a spatially separated way on a removable reactor bottom plate.
2. The method according to claim 1, wherein the reaction mixtures are reacted in the form of solutions or suspensions in the microreaction chambers, which are introduced into the reaction plates in the form of isolated cavities as bores, at temperatures of up to 1000 °C and internal pressures of up to 1000 bar.
3. The method according to claim 1, wherein the solids deposited on the reactor bottom plate are subsequently freed from the supernatant liquid phase and calcined.
4. The method according to claims 1 to 3, wherein the reactor bottom plate, which consists of a material that scatters X-rays elastically, is identical with the library substrate on which the solids are adhesively deposited and constitutes the materials library together with the deposited calcined solids.
5. The method according to claims 1 to 3, wherein a subset of all solids deposited is subsequently transferred to a plastic sheet made of a X-ray transparent material and provided with an adhesive coating, which plastic sheet as a library substrate constitutes the materials library together with the solids transferred thereto.

6. The method according to claims 1 to 5, wherein the solids of the materials library are subsequently characterized by non-destructive analytical methods.
7. The method according to claim 4, wherein the reactor bottom plate consists of a single-crystal slice, preferably of Si, Cu, quartz, rutile, anatase, zirconia, Ge, Al, sapphire, Fe, Ti, Zr, Co, Ni or Sn.
8. The method according to claim 7, wherein the reactor bottom plate consists of a (711) Si single-crystal wafer.
9. The method according to claim 4, wherein reflecting microarea X-ray diffraction is employed as an analytical method.
10. The method according to claim 5, wherein penetrating microarea X-ray diffraction is employed as an analytical method.
11. The method according to claim 5, wherein Kapton, Kevlar, Teflon, Mylar, PVC, polyethylene, polypropylene, polycarbonate, Al, Be or Mg in a layer thickness of < 100 μm is employed as said X-ray transparent material.
12. The method according to claim 5, wherein said layer thickness is below 10 μm .
13. The method according to claim 1, wherein said reactor has a layered design, essentially comprising: a reactor bottom plate, on top thereof a lower part of the reaction plate, made of an inert material, having bores of from 0.05 to 20 mm in diameter, on top thereof an upper part of the reaction plate, made of a hard material, having identical bores, on top thereof a sealing layer, on top thereof a layer of a hard material with which the reactor layers are compressed and sealed using suitable devices.
14. The method according to claim 13, wherein said inert material consists of Kapton, Teflon, graphite, Kevlar, Mylar or steel.

Abstract

The present invention relates to a method for the wet chemical preparation of materials libraries consisting of a large number of solids, the solids being deposited from reaction mixtures in microreaction chambers onto a bottom plate which simultaneously serves as the library substrate. Depending on the material selected for the library substrate, the solids can subsequently be examined non-destructively, for example, by reflecting or penetrating microarea X-ray diffraction.

- Figure 1: Special embodiment of the reactor as employed in the Example.
- Figure 2: Identification of the materials library. The compositions of the individual sample spots are summarized in Table 1.
- Figure 3: On the top of this Figure, there is shown the X-ray diffraction diagram of a conventionally prepared TS-1 zeolite as an example, and below, the identical X-ray scattering images are shown as obtained from the materials library at the stated spots from total amounts of substance in the μg range, proving that crystalline inorganic materials such as zeolites can be prepared and identified by the stated method.

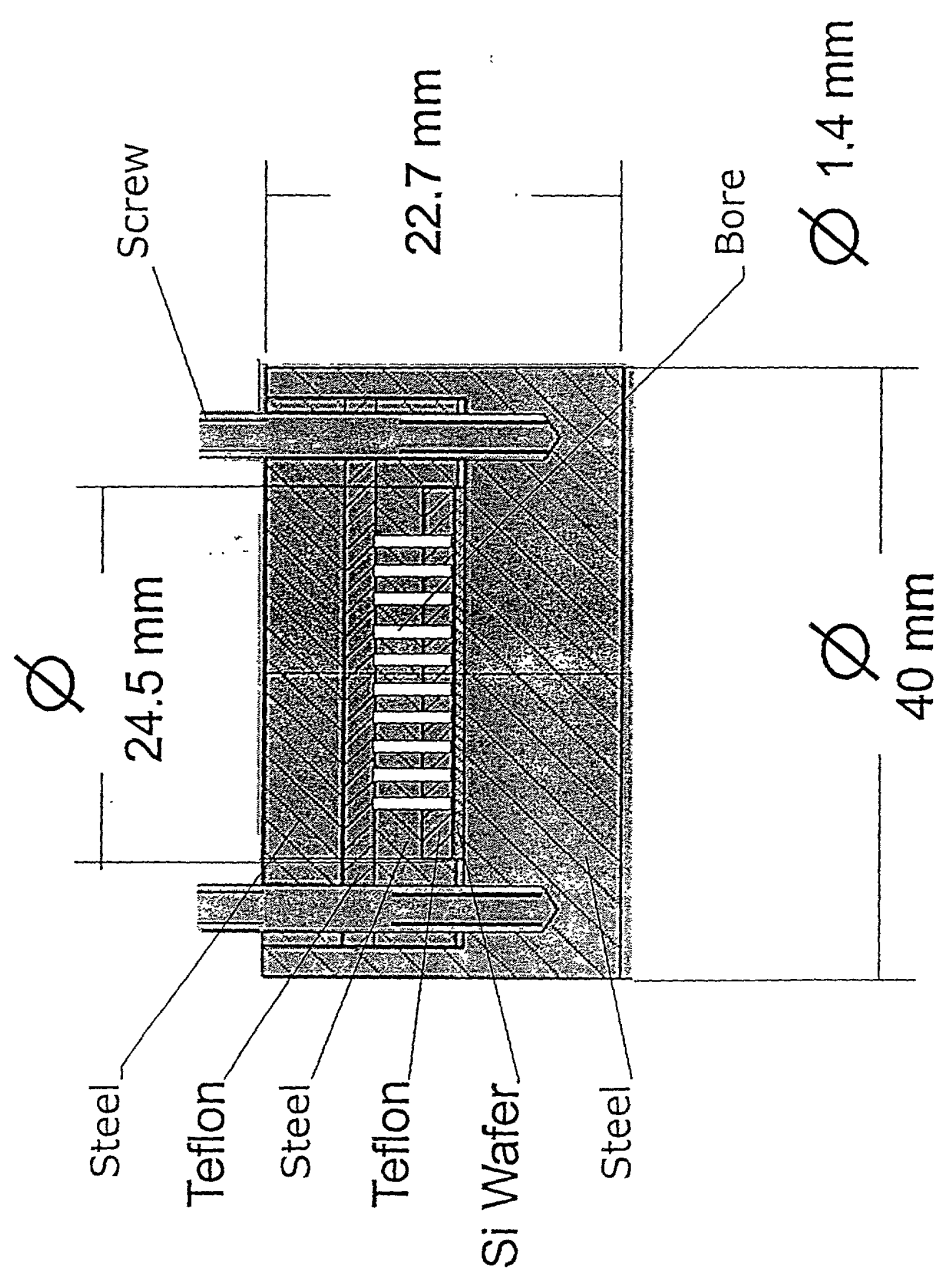


Figure 1

Figure 2

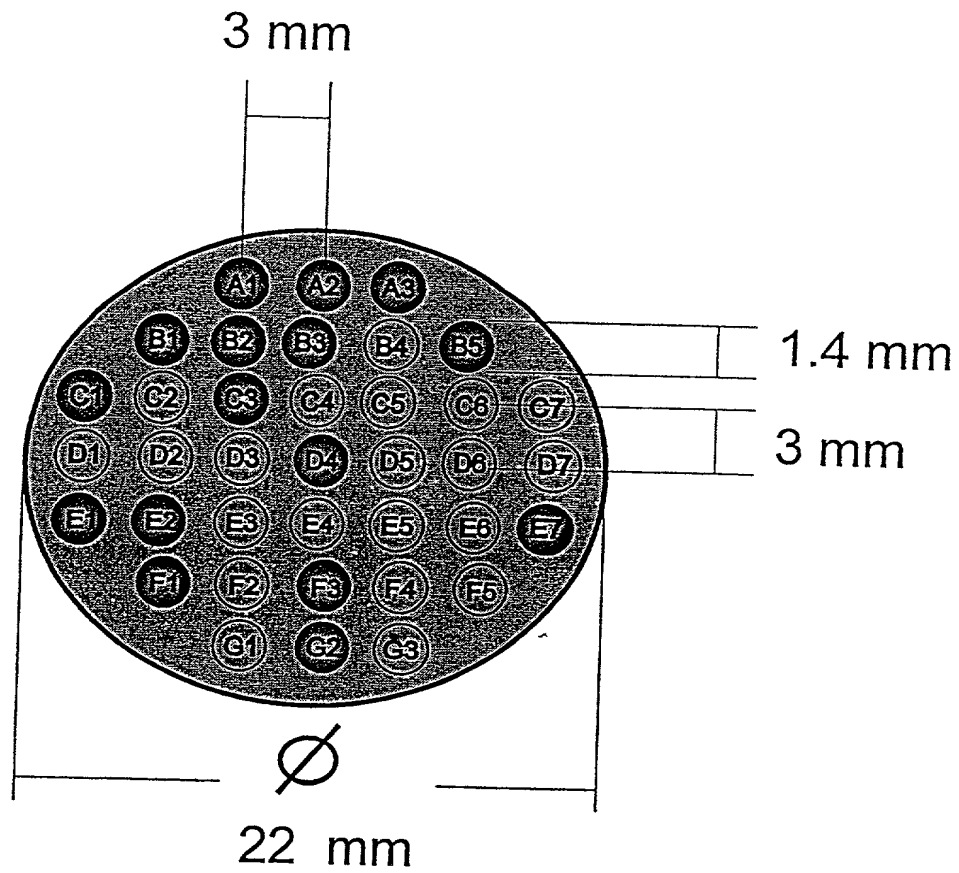
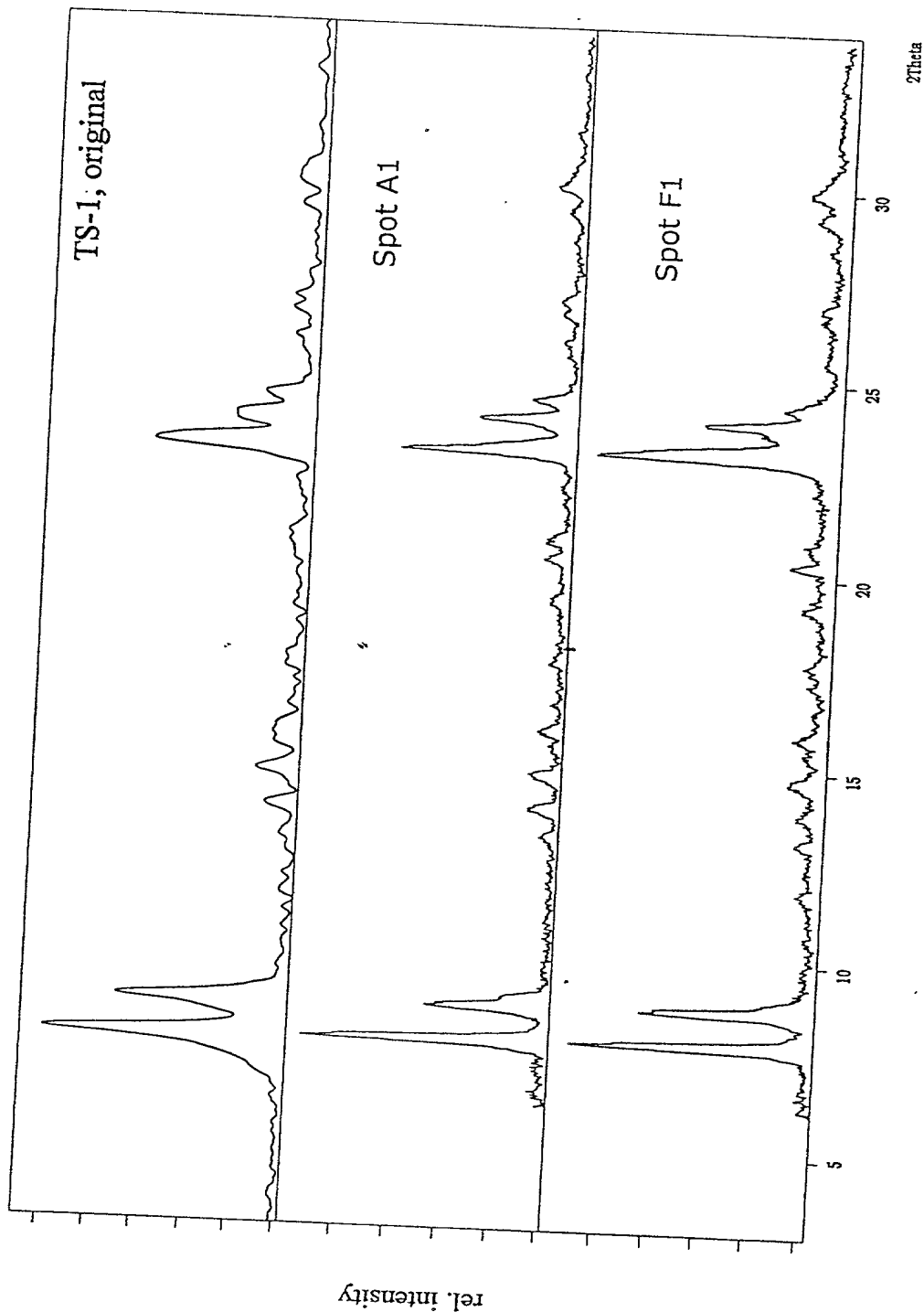


Figure 3



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claim

6. The method according to ~~claims 1 to 5~~, wherein the solids of the materials library are subsequently characterized by non-destructive analytical methods. ✓
7. The method according to claim 4, wherein the reactor bottom plate consists of a single-crystal slice, preferably of Si, Cu, quartz, rutile, anatase, zirconia, Ge, Al, sapphire, Fe, Ti, Zr, Co, Ni or Sn.
8. The method according to claim 7, wherein the reactor bottom plate consists of a (711) Si single-crystal wafer.
9. The method according to claim 4, wherein reflecting microarea X-ray diffraction is employed as an analytical method.
10. The method according to claim 5, wherein penetrating microarea X-ray diffraction is employed as an analytical method.
11. The method according to claim 5, wherein Kapton, Kevlar, Teflon, Mylar, PVC, polyethylene, polypropylene, polycarbonate, Al, Be or Mg in a layer thickness of < 100 µm is employed as said X-ray transparent material.
12. The method according to claim 5, wherein said layer thickness is below 10 µm.
13. The method according to claim 1, wherein said reactor has a layered design, essentially comprising: a reactor bottom plate, on top thereof a lower part of the reaction plate, made of an inert material, having bores of from 0.05 to 20 mm in diameter, on top thereof an upper part of the reaction plate, made of a hard material, having identical bores, on top thereof a sealing layer, on top thereof a layer of a hard material with which the reactor layers are compressed and sealed using suitable devices.
14. The method according to claim 13, wherein said inert material consists of Kapton, Teflon, graphite, Kevlar, Mylar or steel.

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COMBINED DECLARATION AND POWER OF ATTORNEY

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As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name. I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

COMBINATIONAL METHOD FOR MICROGRAM-SCALE PRODUCTION AND CHARACTERIZATION OF CRYSTALLINE AND AMORPHOUS LIBRARIES OF MATERIALS
the specification of which is attached hereto,

or was filed on May 12, 1999

as Application Serial No. 09/700,401

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims.

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s), the priority(ies) of which is/are to be claimed:

198 22 077.4	Germany	05/16/1998
(Number)	(Country)	(Month/Day/Year Filed)

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose the material information as defined in Title 37, Code of Federal Regulations, §1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

PCT/EP99/03287	05/12/1999	pending
(Application Serial No.)	(Filing Date)	(Status)
		(patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status)
		(patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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